HEAD RECONSTRUCTION AND LOCALIZATION OF BRAIN ACTIVITY USING BAYESIAN EVIDENCE

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Abstract - **This study is devoted to a detection of evoked potentials in a brain activity with aim to map these potentials onto a scalp. In this case, there is necessary to focus recorded scalp potentials, which are blurred due to scalp attenuation and, moreover masked by a brain activity. The aim is to estimate the foci of active regions of the brain during evoked potentials.**

Our suggested approach is based on the use of Bayesian evidence to detect potentials in background noise (brain activity). New formula evaluating the Bayesian evidence suitable for this purpose is derived, tested and verified on artificially generated and real data. This method can be used to detect evoked potentials in a brain activity up to signal to noise ratio approximately – 25 dB. This value corresponds to a real situation when potentials are measured on the surface of scalp. The main advantage of the method is the ability to detect evoked potential without any averaging. On the other hand this method cannot reconstruct the shape of evoked potential. Computational costs are very low and enabling the real-time implementation.

Keywords - **Localization of Brain Activity, Head Reconstruction, Bayesian Evidence, Bayesian Model, Signal Detection.**

I. INTRODUCTION

Electroencephalography (EEG) is a well-established method in clinical and experimental study of brain functions. The EEG recordings impose minimal constraints upon the subject, and EEG potentials provide a fine temporal and spatial resolution. The EEG potentials, which are recorded on the scalp, represent the summated excitatory post-synaptic potentials of cortical neurons. The possibility to localize active regions in the cortex is based on synchronous firing of 10^5-10^6 neurons. To match the potential distribution of EEG potentials to the underlying cortical generators, the EEG potentials can be displayed on the head surface, which is approximated either as a sphere or as a realistic head, reconstructed from magnetic resonance images (MRI).

The cortical potentials are highly attenuated during their passage to the scalp electrodes through various tissues, especially by the highly resistive scull. Thus, the recorded scalp potentials are blurred and do not lent themselves for disentanglement of two closely spaced foci of activation. We used Bayesian approach to improve spatial resolution in artificially generated data. A single radially oriented dipole was analyzed in noise environment simulated by thousand dipoles with fixe locations and random dipole moments.

II. MODEL SIMULATION AND HEAD RECONSTRUCTION

A. Model simulation

A 4-shell sphere model (brain, CSF, skull, scalp, $r_{sphere}=1$) of the head served as the volume conductor model. Dimensions of the sphere are determined from positions of real measured EEG electrodes with MMSE (minimum mean square error) algorithm that minimizes distances between the sphere and electrode positions. Potential of a dipole is calculated using eq. 2 of [1]. To simulate background activity of the brain 1000 random radial oriented dipoles were uniformly distributed on a sphere with radius r=0.75. The moment of each dipole had a uniform distribution with a standard deviation δ. The evoked potentials were simulated as a field of one dipole with time varying dipole moment - Fig 1.

B. Head reconstruction

To reconstruct the head in 3-D, the head contours are detected in each sagittal MRI (Siemens Magnetom Vision - Erlangen, Germany) slice. The contour extraction is semiautomatic. The operator chooses the intensity threshold and the contours are determined using the region growing algorithm – Fig. 2. The images are spatially filtered to improve the signal to noise ratio.

The 3-D head model is reconstructed from the extracted contour with deformable mesh - balloon. This method considers the global properties of the reconstructed surface in contrast to the standard approach that is based on the connection of the nearest point from the neighboring slides. In initial phase an approximation of the balloon (sphere) is constructed. Then each point of the balloon is moved in direction of the normal in this point and inside the balloon. The movement of a point is stopped when it reaches the surface of the slice. The result of the balloon model reconstruction is depicted in the Fig 3.

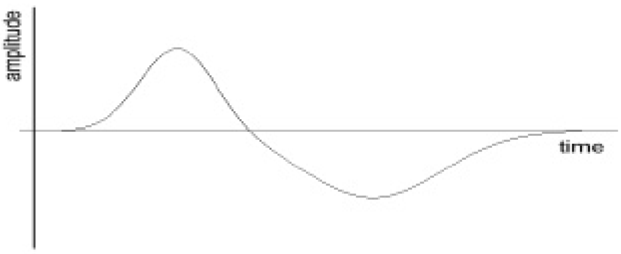

Fig.1. Time evolution of the dipole moment - clean potential in one channel

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Abstract

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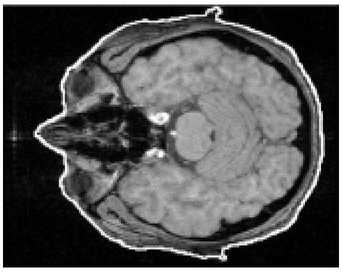

Fig. 2. Contour extraction from MRI slice

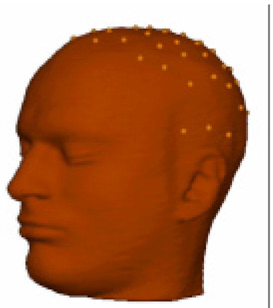

Fig. 3. Head reconstruction from MRI slices

C. EEG Interpolation

Mapping of EEG potentials on the head surface reconstructed from slices MRI is preferable for a more accurate localization of the brain activity. We used the method of interpolation, which is based on spline functions (3Dm splines [2]). To apply the spline interpolation we have to: 1) match the coordinate systems of electrodes with the 3-D head model; 2) find positions of all electrodes in the model.

At the beginning of each measurement of electrode positions the coordinate system is determined by positions of 3 reference points – the nasion (Nz), the left (LPA) ant the right (RPA) preacuricular points. After reconstruction of 3-D model the operator marks reference points in 3-D model with a computer mouse and the proposed efficient algorithm finds the locations of electrode positions.

III. BAYESIAN INFERENCE

The detection of evoked potentials in a brain activity can be seen as a detection of a signal in a random noise. The common approach to reveal evoked potentials is based on the averaging of EEG epochs. This approach yields the reconstructed shape of evoked potentials. But, for the purpose of mapping potentials onto a scalp it is not needed to reconstruct the shape of potentials. Rather than the shape of potential the maximum amplitude is needed for the mapping onto a scalp. Therefore the task is to estimate the maximum amplitude of evoked potential for each EEG signal picked up by the respective electrode. The suggested approach is based on using Bayesian evidence to get an estimate of maximum amplitude of evoked potential for each electrode. This estimate as will be shown is almost independent on the potential to the background noise ratio.

A. Model selection

A general linear model given in [4] was chosen. This model can be written in the form of matrix equation:

$$\mathbf{d} = \mathbf{G} \cdot \mathbf{b} + \mathbf{e},$$

where $\mathbf{d}$ is an N x 1 matrix of data points, $\mathbf{b}$ is M x 1 linear coefficient vector, $\mathbf{e}$ is N x 1 vector of noise samples, and $\mathbf{G}$ is N x M matrix whose columns are the basic functions evaluated at each point in the time series.

After analysis of its behavior [5] suitable models for the detection of signal in noise was suggested. For the purpose of our study the simplest model consisting of a constant signal in random Gaussian noise was used.

The Bayesian evidence (probability of the data $\mathbf{d}$ given the model M) is computed by integrating over unknown parameter values w and generally may be written as

$$p(\mathbf{d} \mid M) = \int p(\mathbf{d} \mid w, M)\, p(w \mid M)\,\mathrm{d}w\,.$$

The evidence for our simplest model will be maximum if only noise is present in the channel. Decreasing of the evidence shows the presence of the evoked potential - higher amplitudes of potentials give us lower value of evidence. From this reason we use the inverse values of the Bayesian evidence.

B. Closed form expression for evidence

After the marginalisation of nuisance parameters the closed form of Bayesian evidence is [6]

$$p(\mathbf{d} \mid M) \approx k \frac{\Gamma(\frac{M}{2})\Gamma(\frac{N-M}{2})(\mathbf{d}^T\mathbf{d} - \mathbf{f}^T\mathbf{f})^{-\frac{N-M}{2}}}{p^{\frac{N}{2}}(\hat{\mathbf{b}}^T\hat{\mathbf{b}})^{\frac{M}{2}} \cdot \sqrt{\det(\mathbf{G}^T\mathbf{G})}},$$

where

$$\hat{\mathbf{b}} = (\mathbf{G}^T\mathbf{G})^{-1}\mathbf{G}^T\mathbf{G}, \text{ and } \mathbf{f}^T\mathbf{f} = \mathbf{d}^T\mathbf{G}(\mathbf{G}^T\mathbf{G})^{-1}\mathbf{G}^T\mathbf{d}\,.$$

In our case the model consisting of constant in noise has parameters as follows: $M = 1$ and $\mathbf{G} = [1\ 1\ 1.\ .\ .\ .\ .\ 1]^T$.

Using the substitution of inner products

$$\mathbf{d}^T\mathbf{d} = \sum_{i=1}^{N} d_i^2\,,\ \mathbf{d}^T\mathbf{G} = \sum_{i=1}^{N} d_i\,, \text{ and } \mathbf{G}^T\mathbf{G} = N\,,$$

we obtain the simple form of logarithm evidence

$$p(\mathbf{d} \mid M) \approx$$

$$\approx -\log\sum_{i=1}^{N} d_i - \frac{N-1}{2}\log\left(\sum_{i=1}^{N} d_i^2 - \frac{1}{N}\left(\sum_{i=1}^{N} d_i\right)^2\right). \quad (1)$$

IV. EXPERIMENTAL RESULTS

In this section the illustration of obtained results are given. Fig. 4. depicts simulated evoked potentials without noise (clean potentials) in each channel given by the respective electrode. These signals serve as the reference.

Fig.5. shows the maxima of potentials in channels computed from signals depicted in Fig.4.

The final map of all potentials on the scalp is shown in Fig.6.

Next three figures are repeated for noise potentials with various potential to noise ratios: 23,0,-23 dB. These ratios are evaluated for potentials with highest amplitudes. Figs. 7-9 show the tested signals (noise potentials) given by a mixture of potentials and noise simulating a brain activity.

Fig. 10 depicts standard mapping the noise signal for –23 dB.

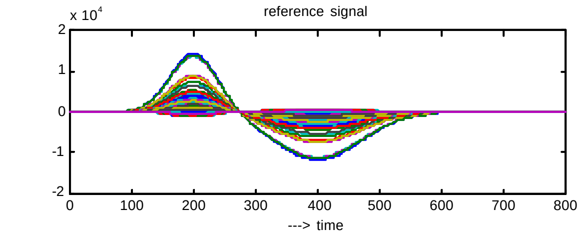

Fig. 4. Reference clean potentials in 82 channels

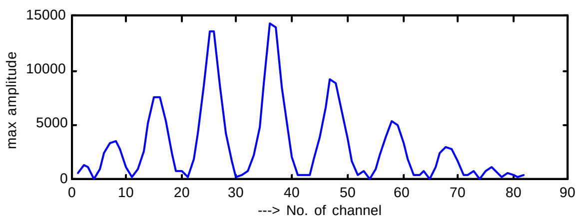

Fig. 5. Amplitudes of reference potentials in respective channels

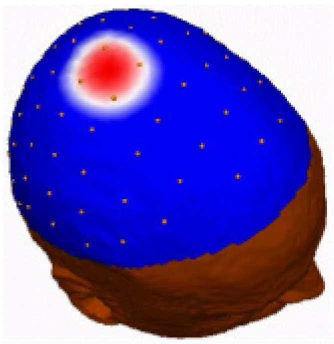

Fig. 6. Reference standard mapping of clean potentials

Figs. 11-14 illustrate the inverse evidence computed according Eq.(1). An inspection of these figures suggests that shapes of the inverse evidence are very close to the shape of potentials amplitudes in Fig. 4. Therefore one can expects good results in mapping. The error in the estimation of maximum amplitudes is about 5 % for 0 dB and 15 % for – 23 dB. These estimation errors cause slight shifts in the position of the brain activity.

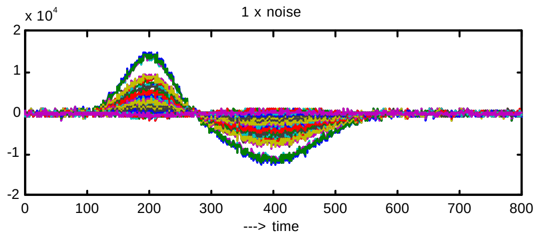

Fig. 7. Noise potentials (23 dB)

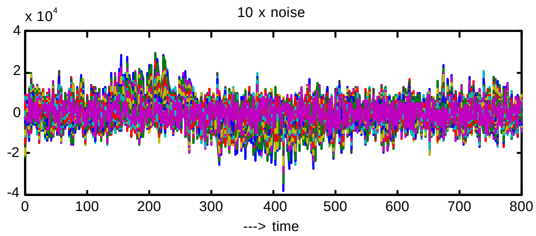

Fig. 8. Noise potentials (0 dB)

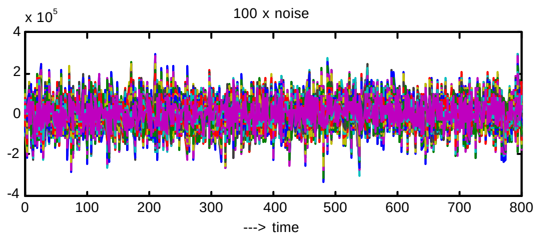

Fig. 9. Noise potentials (-23 dB)

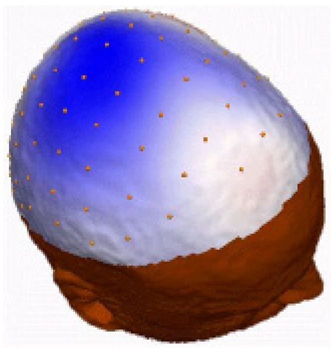

Fig. 10. Standard mapping of noise potentials (-23 dB)

Fig. 14 shows the result gained by mapping the noise signal for –23 dB using Bayesian evidence. The comparison this figure with Fig.6 (reference mapping) and Fig.10 (standard mapping) reveals a great improvement and at the same time the small distortion of the final potentials map.

The method was tested also for real signals. Results were comparable to mapping proceeded by EEG averaging.

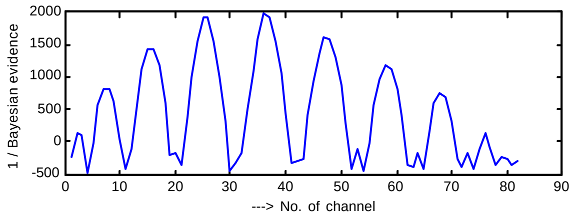

Fig. 11. Inverse evidence of noise potentials (23 dB)

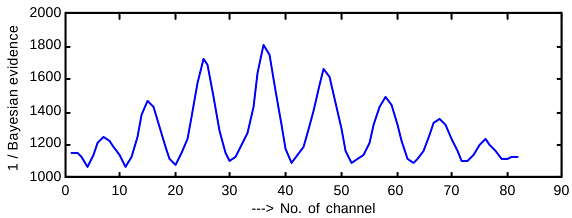

Fig. 12. Inverse evidence of noise potentials (0 dB)

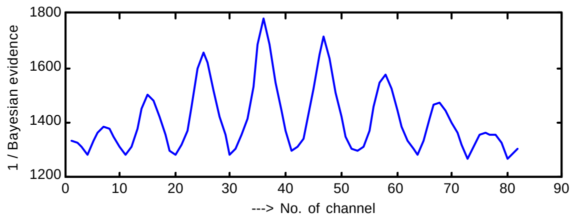

Fig. 13. Inverse evidence of noise potentials (-23 dB)

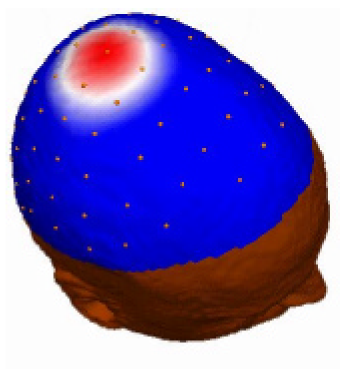

Fig. 14. Mapping of noise potentials (-23 dB) using Bayesian evidence

V. Conclusion

The new robust method for the detection of evoked potentials in a brain activity was introduced. This method is computationally very attractive and suitable for real-time processing. Moreover, it is able to detect evoked potential even from one signal realization. The resulting maps of potentials onto a scalp surface are almost independent on the ratio of evoked potential and noise powers. Therefore the described approach can be used as a preprocessing for the localization of brain activity and head reconstruction. Further research will be focused on the reconstruction of the whole shape of evoked potentials. Bayesian techniques gave some encouraging results in this application.

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